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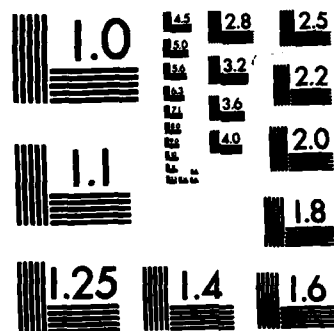
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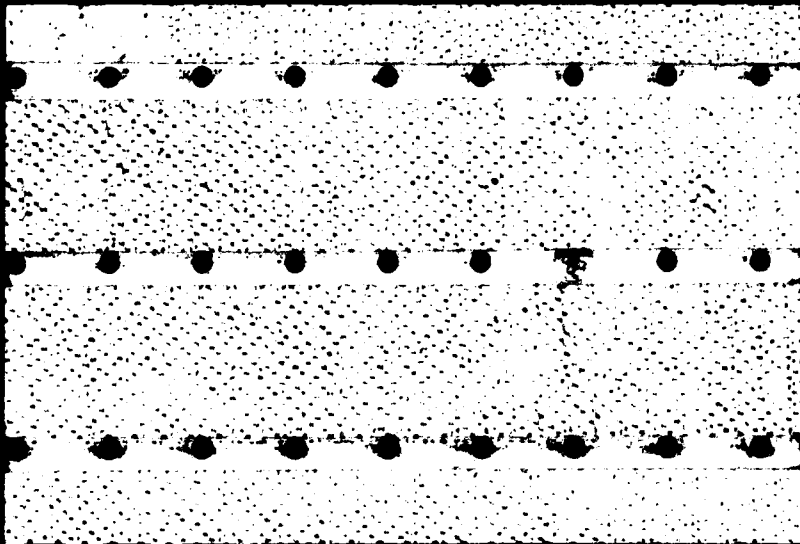
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by

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PROJECT SCHEDULING WITH RESOURCE CONSIDERATIONS

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ABSTRACT: A great deal of research in activity network based project resource management seems not to have found wide spread adoption. We briefly consider why this is true and pose some new research problems.

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INTRODUCTION

In the past twenty-five years, literally hundreds of research papers have addressed in some measure the application of quantitative techniques to problems of resource management in project planning and scheduling. The models and analyses that have found wide spread acceptance and application in practice, however, are few in number, relatively simple, and among the first to appear in the literature. Why should this gap exist between the available research results and their adoption in practice?

The thesis advanced here is that more recent research results have not been adopted because their value to practitioners has not been demonstrated. Certainly, there are economically significant resource management problems that could be better solved. The conclusion is that as researchers either we have failed to adequately "sell" our research results or, worse, we have researched the wrong problem.

A strong case can be made for the argument that we have over-researched some problems that are of limited interest, and have failed to research some problems of greater practical interest. To develop this argument, we will first briefly review the major research contributions to resource management in project planning and scheduling, and then pose some real but as yet unresearched problems.

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SOME RESEARCHED PROBLEMS

Research in activity network based project resource management has generally addressed one of four problem paradigms: time-cost tradeoff, limited resource scheduling, resource smoothing, or long range planning. In all four, it is assumed that the activities and their precedence relationships are given, along with specifications of durations, resource consumption rates, costs, and the relationships between duration and cost for each activity. Each of these paradigms is considered below. It should be understood that our presentation is not intended to be an exhaustive survey, but a representative sample.

TIME-COST TRADEOFF

In this problem paradigm, activity durations may be compressed below their optimum, but at some additional cost. There are costs associated with total project duration, and the problem is to determine the individual activity durations for which total project cost is minimized, for each possible project duration. Research on this problem seeks to develop computationally attractive solution methods for various forms of the activity time-cost tradeoff function.

For the case of linear tradeoff functions, the problem is well solved. Phillips and Dessouky [14] present a simple network model for generating the project time-cost tradeoff curve, and Tufekci [19] gives an efficient solution procedure using the network maximum flow algorithm. A considerable research effort (see, e.g., [5,6,7]) has considered other forms for the tradeoff functions, but solution procedures for these cases are not attractive because of computational requirements.

The time-cost tradeoff problem is rarely treated by commercial project planning/scheduling software packages (see the survey in [15]). In many, if not most applications, the estimates of activity parameters are crude at best. In such situations, it is futile to attempt to estimate the marginal cost to compress a duration. Moreover, activity durations are hardly ever continuously variable, so the applicable tradeoff form leads to unattractive solution times.

A final criticism of this problem paradigm is that it addresses cost, but not resource feasibility. In most practical settings, the tradeoff involves varying the application of resources, which in turn generates the additional cost. Resources are almost always available in limited amounts or rates, which the time-cost tradeoff problem conveniently ignores. Thus, the solution may not be feasible.

LIMITED RESOURCE SCHEDULING

In this problem paradigm, activity durations and resource usage rates are fixed, and the availability of one or more resources is limited. The problem is to determine a resource feasible schedule that minimizes the project completion time.

A number of optimizing algorithms have appeared in the literature; see, e.g., the survey in [1], and more recently [12,13,16,17]. While this has been fertile ground for research, the results have been uniformly discouraging. At this point in time, there is no algorithm that can consistently solve problems with 50 activities or more with reasonable computational effort.

Naturally, research on heuristic solution methods has been popular, as shown by the extensive bibliography in the 1973 survey by Davis [4]. Since that time other heuristics have been proposed, e.g., [3,18]. Almost all heuristics for limited resource scheduling have the same fundamental structure, i.e., they are "dispatching procedures," where the particular rule used to select the activities to dispatch is the distinguishing feature.

Most commercial packages incorporate some form of "resource allocation" and are thus capable of providing solutions to the limited resource scheduling problem. So the limited resource scheduling paradigm is probably a more useful model than the time cost tradeoff paradigm. Nevertheless, it, too, has serious deficiencies. The most serious, perhaps, is the assumption that resources are available at a constant rate. A more realistic assumption is that the resource availability profile has the form of a life cycle curve. Heuristics developed for the traditional problem cannot cope with this type of curve. Where they fail is in guaranteeing feasibility when resource availability is declining.

The traditional statement of the limited resource scheduling problem also precludes varying activity durations to achieve better resource utilization. This seems particularly restrictive in the planning mode, since estimates of labor content for a job may not necessarily fix the duration.

RESOURCE SMOOTHING

In the third problem paradigm, activity durations and resources usage rates are fixed, and there are no limits on the instantaneous rate of resource usage. The problem is to determine the minimum duration schedule

that minimizes the resource "cost" where cost can be associated with maximum resource usage or with changes in resource usage.

Two classical heuristic approaches to the smoothing problem are [2] and [9]. In addition, an optimization approach is described in [10], although it is not useful for large problems. The resource smoothing problem, strangely, has attracted very little research interest compared to limited resource scheduling.

Part of the problem stems from the difficulty of defining a general criterion. In addition, the basic model is inappropriate in situations where resources must be committed uniformly, i.e., availability cannot fluctuate over short intervals. As with limited resource scheduling, the traditional statement of the smoothing problem precludes varying activity durations or resource requirement rates.

LONG RANGE PLANNING

This final problem paradigm allows activity durations and resource usages to vary, allows some activities to be split (i.e., interrupted and restarted), and may allow additional resources to be obtained at some pre-specified cost. The problem is usually to minimize the total cost of the project, where costs may arise from extending project duration, from varying resource availability, etc.

Only heuristic methods have been proposed for this most general problem, and RAMPS [8,11] and SPAR [20] are the two best known. In fact, few, if any, publications in the past 15 years have addressed this general problem.

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OBSERVATIONS

Very little research has directly addressed the long range planning problem, which would seem to be the most useful of the four problem paradigms. Research seems to concentrate on those problems that are simple to state. While this appears to be a reasonable approach, it does have its pitfalls. Suppose, by analogy, we focused research efforts on a general model of production control. We might learn a great deal in this way about the general nature of production control problems. Unfortunately, we probably wouldn't be able to solve specific production control problems, because each one has its own special attributes and characteristics.

So it is with project resource management. In addition to algorithms based on general paradigms, there may be other tools that we need in order to solve specific problems.

SOME UNRESEARCHED PROBLEMS

The problem paradigms discussed above have at least two significant limitations. First, they represent extremely simplified abstractions of the real problems they model. Second, they are all models for project analysis, i.e., they require the basic network structure to be given. The discussion to follow will outline some previously unresearched problems, whose solution we conjecture would improve the usefulness of quantitative techniques for project resource management. Two of these problems focus on the development, or synthesis, of the basic network, while the other two focus on more realistic models of project resource allocation. These problems are not claimed to be the most important unsolved problems in project resource management, simply characteristic of some of the problems that need to be addressed.

ACTIVITY DEFINITION

A common project planning scenario is the following. After contract award, detailed designs are completed by each of the systems design groups, such as HVAC, plumbing, electrical, etc. These designs are the basis for the work breakdown structure, which in turn, devolves into the production work orders. In this system work breakdown structure (or SWBS) the work orders are specific to each system, even though the work may take place in a physical location that is common to several different systems.

With SWBS, a production activity that involves several different systems requires a supervisory mechanism to coordinate the several different work orders. A product oriented work breakdown structure (or PWBS) on the other hand, would generate work orders that corresponded more closely to actual production. Thus, the PWBS concept underlies the development of the basic network for the problem paradigms.

The problem is that when design, engineering, and planning have a SWBS orientation, it is difficult, if not impossible to make an explicit translation to PWBS oriented project network. The development of useful tools for assisting in this translation would do much to improve the general acceptance of network based resource management. With the widespread advent of CAD, this would seem to be a ripe research area.

NETWORK DEFINITION

The four problem paradigms take the basic activity network structure as a given. In many situations, however, the precedence structure itself involves explicit decisions. Consider, for example, ship construction. Ships consists of steel and "everything else," referred to as outfitting. The hull is usually assembled in hull blocks in an assembly area, and then lifted or translated onto the ship erection site.

Some types of outfitting can be done either in the assembly area or the erection site. Choosing one or the other "mode" of outfitting induces particular precedence relationships. If the outfitting is done on block, it must be completed prior to block erection. If it is done on board, it cannot be done until after the block erection is complete, and it is safe to work in the block.

The key is that the activity itself is relatively unchanged, although its cost and duration may be, by shifting between the two modes. The choice of mode impacts resource requirements and perhaps schedule duration, thus is an important management decision. This situation is not unique to shipbuilding, and it is mildly surprising that this type of problem has not been previously addressed.

RESOURCE MODELS

The four problem paradigms allow unlimited resources or finite but constant resource availability. In practice, however, it is often necessary to commit specific resources at specific points in time. The most effective resource commitment profile usually resembles a life cycle curve.

Suppose resource availabilities are given in this form, i.e., increasing to a maximum, and then declining toward the end of the project. Currently, there is no general model or solution procedure for such a problem paradigm.

It is important to note that feasibility itself may be quite difficult to show for such a problem. Therefore, the model may have to incorporate some notion of feasibility recovery. This also is a problem that has received no attention in literature.

Suppose that the problem with life cycle type resource availability could be solved. Now consider the typical multiproject environment where a common pool of resources must be committed, over time, to projects now underway, projects already on the books, and new projects being considered. What coordinating mechanism can be used to determine the individual project durations, completions, and resource profiles?

LONG RANGE PLANNING

The long range planning paradigm presented earlier required very detailed scheduling decisions and results. In practice, long range planning rarely considers this level of detail. Instead, the objective is to determine if, generally speaking, this project can be accomplished with this resource availability. Clearly, some consideration must be given to scheduling -- the issue is the level of detail necessary.

Feasibility for long range planning requires only that, if the given resource commitments is not adequate, only "reasonable" adjustments will be needed. There are no models for this problem in the literature. Perhaps there can be no general model, because so much of the problem depends on individual circumstances, past practice, etc. However, this does appear to be a topic open to research.

CLOSURE

Based on a broad look at research in project resource management, one fact seems certain. All previous research has focused on a problem paradigm abstracted from its original source. Thus, no consideration is given to the problem environment. This seems to be a fundamental error. Without considering some aspects of the problem environment, how can we develop problem specific tools? Or, how can we develop general tools that

will allow the manager or analyst to gain access to the general models and results in a useful and meaningful way?

The abstraction from problem environment also has lead us to focus on analysis to the exclusion of synthesis. We've taken the relatively easy analysis problem and solved it in great detail, without any thought to the difficult design problem.

Future research in project resource management should focus on the design aspect of project networks and on a set of general tools that are useful in specific problem environments.

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